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SUPPLY SUPPORT

OF NASA TRACKING NETWORKS

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## SUMMARY

This report addresses two areas:

(1) Whether and to what extent should supply support for Jet Propulsion Laboratory's Deep Space Network and Goddard Space Flight Center's Space Flight Tracking and Data Network be consolidated.

(2) Identification of opportunities for improvements in each of the supply systems without regard to consolidation.

There is a considerable amount of commonality between the items in the stock catalogs at the two network depots, 58% for federal stock number items and 30% overall. The workload at the DSIF Supply Depot (DSD) is small (less than 20%) compared to the Network Logistics Depot (NLD). A number of important benefits in supply support would result from a consolidation of DSD into NLD.

LMI found that a consolidation "as is," without any changes in inventory management techniques, would reduce annual operating costs by from $208,000 to $358,000. However, if the consolidation were coupled with a change to use of economic order quantities, the annual operating cost reduction would range from $930,000 to $1,078,000.

The consolidation "as is" reduction results from eliminating the $633,000 cost to operate DSD less increased costs at the Network Logistics Depot to absorb the increased workload. When the consolidation is effected with EOQ, there would be the $633,000 savings from DSD plus cost reductions at NLD because of a net 19% decrease in issues and a 21% decrease in

receipts (after taking on DSD's workload). In addition, there would be a one-time inventory reduction of about $275,000. Supply effectiveness would increase because the number of stock-outs would decrease by about 45% on recurring demand items. The report recommends that prompt action be taken to effect the consolidation and outlines an approach. The one-time cost to consolidate is estimated at about $100,000. LMI also recommends that the supply support of the various stations at Goldstone, California, be consolidated and that consideration be given to consolidating supply at other sites where stations are co-located.

LMI identified a number of opportunities to improve the supply support and reduce the operating cost of the tracking networks. The opportunities are grouped into six categories: (1) determination of stock level requirements, (2) initial provisioning, (3) handling of long supply, (4) supply effectiveness, (5) service to sites, and (6) other workload savings.

## TABLE OF CONTENTS


| | | | | Page |
|---|---|---|---|---|
| SUMMARY | | | | ii |
| LIST OF TABLES | | | | |
| LIST OF FIGURES | | | | |
| Section | | | | |
| I. | INTRODUCTION | | | 1 |
| | A. | THE PROBLEM | | 1 |
| | B. | STUDY APPROACH | | 1 |
| | C. | ORGANIZATION OF THE REPORT | | 2 |
| II. | PRESENT SITUATION | | | 3 |
| | A. | INTRODUCTION | | 3 |
| | B. | NETWORK LOGISTICS DEPOT (NLD) | | 3 |
| | | 1. | The Facility | 4 |
| | | 2. | Operating Costs | 4 |
| | | 3. | Workload | 6 |
| | | 4. | Supply Management System | 7 |
| | C. | DSIF SUPPLY DEPOT (DSD) | | 8 |
| | | 1. | The Facility | 9 |
| | | 2. | Operating Costs | 9 |
| | | 3. | Workload | 11 |
| | | 4. | Supply Management System | 12 |
| | D. | NETWORK SITES | | 13 |
| | | 1. | Rosman | 13 |
| | | 2. | Goldstone | 13 |

TABLE OF CONTENTS (Continued)


| | | | | Page |
|---|---|---|---|---|
| III. | CONSOLIDATION | | | 15 |
| | A. | INTRODUCTION | | 15 |
| | B. | CONSOLIDATION OF DEPOTS | | 15 |
| | | 1. | Consolidation "As Is" | 15 |
| | | 2. | Consolidation with Changed Order Quantity Rule | 20 |
| | | 3. | Method and Cost for Consolidation | 28 |
| | | 4. | Other Potential Benefits | 33 |
| | C. | CONSOLIDATION AT SITES | | 34 |
| IV. | A. | INTRODUCTION | | 38 |
| | B. | DETERMINATION OF STOCK LEVEL REQUIREMENTS | | 38 |
| | | 1. | Operating Level (Order Quantity) | 39 |
| | | 2. | Safety Level (SL) | 42 |
| | | 3. | Order and Ship Time (OST) | 43 |
| | C. | INITIAL PROVISIONING | | 43 |
| | | 1. | Determining Requirements | 46 |
| | | 2. | Obtaining and Positioning Material | 47 |
| | D. | HANDLING OF LONG SUPPLY | | 47 |
| | | 1. | Transfer Level (TL) | 48 |
| | | 2. | Reporting Level (RL) | 49 |
| | | 3. | Economic Retention Level (ERL) | 49 |
| | E. | SUPPLY EFFECTIVENESS | | 51 |
| | F. | SERVICE TO SITES | | 53 |
| | G. | OTHER WORKLOAD SAVINGS | | 55 |

TABLE OF CONTENTS (Continued)


| Section | | Page |
|---|---|---|
| V. | POTENTIAL IMMEDIATE ACTIONS TO REDUCE COSTS . . . . . . . . . . . . . . . . | 56 |
| | A. BENEFITS IN FY 1973 . . . . . . . . . . . . | 56 |
| | B. BENEFITS IN FY 1974 . . . . . . . . . . . . | 57 |

APPENDICES

A TASK ORDER NASw 73-T

B LIST OF STDN ACTIVITIES

C DERIVATION OF CONSOLIDATION SAVINGS FACTOR

## LIST OF TABLES


| Table | | Page |
|---|---|---|
| 1 | NLD PERSONNEL BY FUNCTION | 5 |
| 2 | NLD ANNUAL OPERATING COSTS | 5 |
| 3 | INVENTORY MANAGED BY NLD | 6 |
| 4 | STRATIFICATION OF NLD INVENTORY BY COST CATEGORY | 6 |
| 5 | SELECTED WORKLOAD ACTIVITY FOR NLD | 7 |
| 6 | DSD PERSONNEL BY FUNCTION | 10 |
| 7 | DSD TWELVE-MONTH OPERATING COSTS | 10 |
| 8 | DSD STOCK MATERIAL INVENTORY | 11 |
| 9 | SELECTED WORKLOAD ACTIVITY FOR DSD | 12 |
| 10 | COMMONALITY OF CATALOGED ITEMS AT NLD AND DSD | 16 |
| 11 | NLD AND DSD COMPARATIVE DATA | 17 |
| 12 | ESTIMATED PERCENT OF RECEIPTS AND ISSUES TO TOTAL NLD WORKLOAD | 19 |
| 13 | EFFECT OF CONSOLIDATION ON NLD WORKLOAD AND COSTS | 19 |
| 14 | OPERATING COST REDUCTION BY CONSOLIDATION "AS IS" | 19 |
| 15 | ILLUSTRATION OF EFFECT OF USING EOQ | 22 |
| 16 | CONSOLIDATION BENEFIT FACTOR | 24 |
| 17 | EFFECT OF CONSOLIDATION AND EOQ ON RECEIPTS WORKLOAD LINE ITEMS | 25 |

LIST OF TABLES (Continued)


| Table | | Page |
|---|---|---|
| 18 | EFFECT OF CONSOLIDATION AND EOQ ON ISSUE WORKLOAD LINE ITEMS | 26 |
| 19 | OPERATING COST REDUCTION BY CONSOLIDATION WITH EOQ | 27 |
| 20 | MATERIAL SHIPPING SEQUENCE | 30 |
| 21 | INVENTORY AT GOLDSTONE | 36 |
| 22 | EFFECT OF EOQ ON INDIVIDUAL DEPOTS | 39 |
| 23 | NLD SUPPLY EFFECTIVENESS | 51 |
| 24 | NLD PHYSICAL INVENTORY PLAN | 52 |

# LIST OF FIGURES


| Figure | | Page |
|---|---|---|
| 1 | GOLDSTONE SUPPLY SUPPORT SYSTEMS . . . . . . . . | 35 |

# I. INTRODUCTION

## A. THE PROBLEM

The Jet Propulsion Laboratory (JPL) and the Goddard Space Flight Center (GSFC) operate independent supply systems: JPL to support the Deep Space Network (DSN) and GSFC to support the Space Flight Tracking and Data Network (STDN). The Office of Tracking and Data Acquisition (OTDA), the NASA Headquarters office of primary responsibility for the two networks, is seeking a determination of whether and to what extent the two systems should be merged. The objective of such a merger is cost reduction without any degradation of supply support to either network.

The Logistics Management Institute (LMI) was asked by OTDA on 13 November 1972 to examine the problem and to recommend a course of action.[1] Also, during its examination of the primary problem, LMI was to identify opportunities for improvements in each of the supply systems without regard to the merger issue, that is, potential improvements that could be made in each system even though a recommendation was made not to consolidate.

## B. STUDY APPROACH

LMI adhered to the general approach to the study that was included in the task assignment scope of work.

Visits were made to NASA Headquarters, GSFC, JPL, GSFC's Network Logistics Depot in Baltimore, Maryland and JPL's DSIF

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[1] A copy of the Task Order is included as Appendix A.

Supply Depot in Monrovia, California, and two tracking sites: the STDN station at Rosman, North Carolina, and the complex at Goldstone, California. The primary emphasis at Goldstone was on the DSN stations, with only a brief visit to the STDN Apollo station.

Generally, data were available at the time of our visits in accordance with the advance list of desired information. Problems were experienced in obtaining some desired data because of the differences in how the two supply systems are managed, not from any reluctance on disclosure. In fact, we received splendid cooperation throughout our study from the NASA and contractor personnel responsible for supply system operations.

## C. ORGANIZATION OF THE REPORT

An overview of the two supply operations is presented in Section II. It includes workload and cost data about each system that is relevant to the analysis. Our analysis and conclusions with respect to the consolidation of the two depots are in Section III. That section includes an estimate of the cost of, and a suggested procedure for, effecting consolidation. "Other Potential Improvements," Section IV, outlines our thoughts on how the individual supply operations might be improved--independent of the consolidation question. Section V lists some actions that might be taken to achieve immediate expenditure reductions throughout the two systems.

# II. PRESENT SITUATION

## A. INTRODUCTION

This section is an overview of the two depot operations and the network sites that we visited. It is limited to those aspects that have a direct bearing on the question of consolidation or improved management of the individual systems.

The depot at Baltimore, Maryland, providing supply support to the STDN, is referred to as the Network Logistics Depot (NLD). The depot at Monrovia, California, providing wholesale supply support to the DSN, is called the DSIF Supply Depot (DSD).

Factors of interest to the study, such as number of items cataloged, and the number and value of inventory items vary over time in each of the supply systems. While it was clear early in the study that the analysis would not be very sensitive to the modest variations over time that we observed, we used an average value over time for such factors. We attempted to collect data on number of issues, number of receipts, and cost of operations over the 12-month period ending 30 September 1972. In some cases, where 12-month data were not available, we extrapolated from a 9-month data base.

## B. NETWORK LOGISTICS DEPOT (NLD)

NLD is operated by the Raytheon Corporation under an M&O contract to the Goddard Space Flight Center. Raytheon replaced the RCA Service Corporation as the contractor on 1 January 1973.

The NLD provides wholesale supply support to more than 60 locations/sites throughout the world making up the STDN network. A listing of the supported sites and activities is included as Appendix B.

As with the DSD, the NLD primarily is concerned with technical material. While some general and administrative supply items are included in its system, most such supplies are a responsibility of the agency operating the sites. Generally, NLD furnishes such supplies only where they are not available for local purchase overseas.

1. The Facility

The NLD facility, located at Baltimore, Maryland, is leased by NASA and provided to the M&O contractor as government-furnished property. The facility, consisting of two adjacent warehouses, contains some 82,000 square feet--2,400,000 cubic feet. A breakdown of warehouse/administrative space was not obtained. The least cost of the NLD facility to NASA is $136,000 per year. The contractor pays utility costs.

2. Operating Costs

Contractor personnel charged to the M&O contract are shown in Table 1. Annual operating costs for the NLD are shown in Table 2.

In addition to the above, there are seven professional and one clerical employees of GSFC who are engaged full time on contract monitoring. We made no attempt to identify those personnel costs.

TABLE 1

NLD PERSONNEL BY FUNCTION
As of 30 September 1972

| Function | No. of Persons |
|---|---|
| Project Management | 2 |
| Program Control | 4 |
| Project Administration | 5 |
| Project Finance | 8 |
| Project Personnel | 2 |
| Quality Assurance | 7 |
| ADP | 18 |
| Material Management | 14 |
| Inventory Management | 18 |
| Physical Inventory | 12 |
| Research and Standardization | 26 |
| Purchasing | 21 |
| Material Operations | 41 |
| Total | 178 |
| Source: NASA Forms 533 (Attachments) | |

TABLE 2

NLD ANNUAL OPERATING COSTS
Twelve Months Ended 30 September 1972

| Category | $(000) |
|---|---|
| 1. Labor | $ 1,229.5 |
| 2. Overhead | 285.4 |
| 3. Computing & ADP | 265.9 |
| 4. Facility Expense | 63.4 |
| 5. Postage and Freight | 73.6 |
| 6. Communications | 54.0 |
| 7. Miscellaneous | 114.5 |
| 8. G&A and Fee | 478.1 |
| Subtotal | $ 2,564.4 |
| 9. Facility Lease | 136.0 |
| Total | $ 2,700.4 |
| Source: NASA Forms 533 (Items 1 through 8). | |

3. Workload

The amount of inventory managed by the NLD is shown in Table 3. For each category the count, as of 30 September 1972, is shown as well as the average over the preceding twelve months.

TABLE 3

INVENTORY MANAGED BY NLD

| Category | As of 30 September 1972 | Monthly Average 1 October 1971-30 September 1972 |
|---|---|---|
| 1. Line Items of Inventory | 67,840 | 68,250 |
| 2. Value of Inventory | $22,400,000 | $22,300,000 |

No break-out is available of the network spares (reparables) in the inventory. However, some idea can be gained from the cost stratification of the NLD inventory, as shown in Table 4.

TABLE 4

STRATIFICATION OF NLD INVENTORY BY COST CATEGORY
As of 30 September 1972

| Cost Category | Unit Cost | Line Items | | Value | |
|---|---|---|---|---|---|
| | | Number | % | $ (000) | % |
| I | $500 or more | 1,554 | 2.3 | $10,579 | 47.2 |
| II | $ 25 to $499 | 11,157 | 16.4 | 6,718 | 30.0 |
| III | Less than $25 | 55,129 | 81.3 | 5,111 | 22.8 |
| | Total | 67,840 | 100 | $22,408 | 100 |
| Source: GNLD 6-1-51 Report. | | | | | |

It can be fairly assumed that all Category I items are reparable. Some portions of Category II also are in that category. Although reparable items are coded in the inventory management system, we did not believe a special computer run to arrive at a precise count would be worth the cost in this analysis.

Selected workload activity at the NLD is shown in Table 5.

TABLE 5

SELECTED WORKLOAD ACTIVITY FOR NLD
Year Ending 30 September 1972

| Activity | Line Items | Value |
|---|---|---|
| 1. Receipts[1] | 66,000 | $16,400,000 |
| 2. Issues | 109,000 | $14,400,000 |

[1]Includes site returns (reparables, long supply, and misshipments).

Source: GNLD 6-1-34 Report.

4. Supply Management System

The NLD operates as a "pull" system, that is, network sites submit requisitions to the NLD as required to maintain site inventories at prescribed levels. Requisitions are passed to the depot by TWX in a single line item standard format.

A test is being conducted to determine if the network sites should be replenished automatically, that is, by using a "push" system. The test is running for selected items of the Rosman, North Carolina, network site.

The NLD supply management system is computerized and was operated by the M&O contractor (RCA until 31 December 1972) on an RCA Spectra 70/45 computer. The system basically is one developed by RCA for the Air Force more than a decade ago. It has been proven as a system that provides, or can provide, the wide range of information required for modern inventory management.

LMI offers no suggestions with respect to the basic system. In Section IV, "Potential Improvements in Individual Systems," there is included a number of suggested improvements that will further capitalize on the basic capability of the system in use.

## C. DSIF SUPPLY DEPOT (DSD)

DSD is operated by the Philco-Ford Corporation under an M&O contract to the Jet Propulsion Laboratory, which, in turn, is a NASA contractor.

The DSD provides supply support of technical material to the following locations:

| | | |
|---|---|---|
| DSS-41 | - | Woomera, Australia |
| DSS-42 | - | Canberra, Australia |
| DSS-43 | - | Tidbinbilla, Australia |
| DSS-51 | - | Johannesburg, South Africa |
| DSS-61 | - | Madrid, Spain |
| DSS-62 | - | Madrid, Spain |
| DSS-63 | - | Madrid, Spain |
| DSS-71 | - | Cape Kennedy, Florida |
| DSS-91 | - | Goldstone, California (This is a central supply store at Goldstone serving all DSN activities within the Goldstone complex.) |

In addition, limited supply support is provided to a test site at JPL Pasadena, and some material is furnished to engineers at JPL.

Only technical material, referred to as "S-Band material," is supplied to the DSN by DSD. General and administrative supplies are provided to overseas network sites by the host government, or quasi-government agency operating the sites under agreements with NASA. Such supplies are obtained at CONUS sites through local purchase, or in the case of the Goldstone, California site through a combination of local purchase and by drawing from the JPL supply organization.

1. The Facility

The building in which DSD is operated is leased by the M&O contractor from commercial owners. The building contains 33,000 square feet, of which 25,670 square feet are devoted to warehousing operations; the balance of 7,330 square feet is used for administrative purposes. Current plans call for rearranging use to provide 14,400 square feet of administrative space and 18,600 for warehousing. Annual rental cost is $44,556. Automotive equipment, fork lifts, storage equipment, tools, and furniture and fixtures used at the facility are government-furnished and have an approximate acquisition value of $117,000.

2. Operating Costs

The M&O contractor, Philco-Ford, provides a number of services to JPL and has about 700 persons working under the overall contract. Thus, NASA 533 Report data on the DSD, as a discrete operation, are not available. The data presented here were drawn from exhibits prepared for us by the DSD.

Contractor personnel assigned to the DSD operation are shown in Table 6.

TABLE 6

DSD PERSONNEL BY FUNCTION
As of 30 November 1972

| Function | No. | Function (cont'd.) | No. |
|---|---|---|---|
| Management | 2 | Purchasing | 4 |
| Systems & Audit | 4 | Warehouse Operations | |
| Property | 2 | Supervisor | 1 |
| Material Management | | Warehousing | 3 |
| Supervisor | 1 | Shipping and Receiving | 8 |
| Requirements | 6 | Facilities/Stockmen | 2 |
| Material Control | 3 | Part-Time (Equivalent) | 2.5 |
| Communications & Data | 3 | | |
| Catalog & Provisioning | 5 | | |
| | | Total | 46.5 |

Source: DSD Exhibit 13.

Annual operating costs of the DSD are summarized in Table 7.

TABLE 7

DSD TWELVE-MONTH OPERATING COSTS
For Period Ending 30 September 1972

| Category | Cost |
|---|---|
| 1. Personnel | $ 437,000 |
| 2. Computer Services | 84,000 |
| 3. Facility Operations (Lease, Utilities, Utilities, Security, Supplies, Equipment) | 112,000 |
| Total | $ 633,000 |

One JPL person engaged in technical monitoring of the DSD portion of the M&O contract is not included.

3. Workload

The stock material inventory managed by the DSD is shown in Table 8.

TABLE 8

DSD STOCK MATERIAL INVENTORY
During 12-Month Period Ending 30 September 1972

| Category | Line Items | Value |
|---|---|---|
| Network Spares | 5,000 | $5,000,000 |
| Other Material | 16,500 | 859,000 |
| Total | 21,500 | $5,859,000 |

Source: DSD Exhibit 1. Network spares figures were estimated by DSD and JPL personnel.

The DSD also receives, stores, and ships network spares (both reparables and end items). Such material is not managed within the computerized inventory system but on manual stock card records. DSD personnel estimated this material to consist of 5,000 line items with a value of $5,000,000. Thus, in our analyses we use 21,500 line items valued at $5,859,000 as a measure of the inventory managed by DSD.

Selected workload activity is shown in Table 9.

TABLE 9

SELECTED WORKLOAD ACTIVITY FOR DSD
Year Ending 30 September 1972

| Activity | Line Items | Value |
|---|---|---|
| 1. RECEIPTS | | |
| Network Spares | 6,700 | $ NA[1] |
| Other Material | 6,600 | 594,000 |
| Total Receipts | 13,300 | |
| 2. ISSUES | | |
| Network Spares | 5,400 | NA[1] |
| Other Material | 16,000 | $632,000 |
| Total Issues | 21,400 | |

[1]Not available.

Source: Logistics Activity Reports and estimates from DSD personnel.

4. Supply Management System

The DSD uses a push supply system, that is, network site stocks are replenished automatically by the DSD, based upon site issue information. Site issue data are mailed to the DSD weekly by the sites.

The management system, sometimes referred to at DSD as Supply Inventory System, is computerized and runs on the UNIVAC 1108 at JPL. The system initially was designed for an available special purpose computer and was converted to the 1108 without system change. There are a number of deficiencies/weaknesses in the system. JPL/DSD has initiated steps to correct many of them.

The most obvious weakness we observed is that the system does not provide for accumulation and use of historical demand data. In a push supply system that information is of paramount importance. The DSD has been forced to bootstrap to cover this deficiency by use of manual research to develop demand history.

The Supply Inventory System is discussed in more detail and recommendations for improvement are offered in Section IV, "Potential Improvements in Individual Systems."

## D. NETWORK SITES

Two sites were visited: the STDN station at Rosman, North Carolina, and the STDN and DSN stations at Goldstone, California.

### 1. Rosman

The Rosman station maintains an inventory of approximately 23,000 line items with a value of $1,499,000. The station supply store is manned 24 hours per day, with most routine work being done on the normal shift. Eight persons are engaged in supply operations. Rosman personnel estimated that 80% of the line items had no issues during the previous twelve months.

### 2. Goldstone

There are two STDN sites and a number of DSN sites located on the Goldstone "reservation." The two STDN sites (Apollo and Mojave) each look to NLD for technical material support and to local purchase for general supplies. The DSN sites are supported with technical material (S-Band) by a centralized store at Goldstone (DSS-91), which, in turn, is replenished from the DSD. Also, the DSN Network Maintenance Facility is located at Goldstone and draws technical material from both DSS-91 and directly from the DSD. General supplies for the DSN sites are obtained by a centralized store (DSS-92, co-located with DSS-91), which is replenished from the JPL supply department. The supply support of NASA activities located at Goldstone is complex.

The situation is displayed in more detail, together with our recommendations, in Section III.

# III. CONSOLIDATION

## A. INTRODUCTION

LMI recommends that the two depots, NLD and DSD, be consolidated and that NLD be the surviving depot. A simple consolidation would result in modest reduction of about $208,000 annually in operating costs. However, the maximum potential savings to NASA, $930,000 annually in operating costs, reside in a consolidation of the depots in combination with changes in the inventory system to be used by the surviving depot.

We also recommend that supply support at Goldstone be consolidated. Goldstone was the only location visited where STDN and DSN sites are co-located. We recommend that serious consideration be given to consolidating the local supply support function where sites are co-located elsewhere around the world.

## B. CONSOLIDATION OF DEPOTS

### 1. Consolidation "As Is"

The reduction in operating costs if the two depots are consolidated "as is," without changing the order quantity rule, is discussed under this heading. Consolidation with a change in the order quantity rule is discussed under B. 2.

There is considerable commonality of items carried at both depots. A recent JPL Study[1] showed that at least 30% of cataloged items at DSD were also in the NLD catalog. The degree of commonality is shown in Table 10.

---

[1] Preliminary Evaluation of Logistics Material Support JPL-DSIF Operations Goddard Space Flight Center, Jet Propulsion Laboratory; Document No. 337D-5A1, 15 June 1972.

At NLD, 33% of catalog items are carried in stock. Because of the similarity in mission and equipment, it is likely that there is a higher commonality among stocked items, and an even higher commonality among items issued. However, firm data on commonality among stocked items and among issued items at the two depots are not available. Therefore, in this study we use the conservative figure of 30% commonality, except for network spares where DSD estimates a 5% commonality.

TABLE 10

COMMONALITY OF CATALOGED ITEMS AT NLD AND DSD

| | NLD | DSD | Common | % DSD Items to NLD |
|---|---|---|---|---|
| FSN | 83,780 | 13,071 | 7,563 | 58% |
| PSN | 114,970 | 21,843 | 3,031 | 14% |
| Total | 198,750 | 34,914 | 10,594 | 30% |

Source: Preliminary Evaluation of Logistics Material Support JPL-DSIF Operations Goddard Spaceflight Center, Jet Propulsion Laboratory, Document No. 337D-5A1, 15 June 1972.

The inventory and workload at DSD are small compared to NLD. Table 11 shows that DSD has 20% of the receipt and issue workload of NLD. Partly as a result of the smaller workload, it costs more for DSD to perform each unit of work (each line item of issue or receipt) than for NLD. Table 11 shows that for the year ending 30 September 1972, DSD has 20% as many receipts and issues compared to NLD; however, DSD's annual operating cost was 23% of NLD's.

TABLE 11

NLD AND DSD COMPARATIVE DATA
($ Millions)

| | NLD | DSD | % DSD To NLD | Combined | % NLD Increase |
|---|---|---|---|---|---|
| Depot Stock | | | | | |
| Line Items | 68,250 | 21,500 | 32 | 84,550 | 24% |
| Value | $22.30 | $5.86 | 26 | $28.16 | 26 |
| Issues | | | | | |
| Line Items | 109,000 | 21,400 | 20 | 130,400 | 20 |
| Value | $14.40 | $.63[1] | -- | -- | -- |
| Receipts | | | | | |
| Line Items | 66,000 | 13,300 | 20 | 77,000 | 17 |
| Value | $16.40 | $.59[1] | -- | -- | -- |
| Depot Personnel | 178 | 46.5 | 26 | 208 | 17 |
| Operating Cost | $ 2.70 | $.63 | 23 | $3.13 | 16 |

[1]Excludes network spares.

Table 11 presents information on the estimated effect of a consolidation. Assuming a 5% commonality of network spares and 30% commonality for all other stock items, the number of common line items would be 5,200.[1] As a result, there would be 5,200 less line items stocked in a consolidated depot than in two separate depots. Issue workload would not change if present site ordering rules are maintained. The issue workload of a consolidated depot would be the same as the sum of the issues at NLD and DSD. Receipt workload would decrease by the amount of DSD receipts that are for items common to NLD, or

---

| | | |
|---|---|---|
| [1]5,000 line items of network spares x 5% commonality | = | 250 |
| 16,500 line items of other items x 30% commonality | = | 4,950 |
| Total DSD line items common to NLD | | 5,200 |

2,315 less receipts in the consolidated depot than in two separate depots.[1]

To estimate the effect on NLD of a 17% increase in receipts and a 20% increase in issues, it is necessary to determine the proportion of total NLD workload represented by receipts and issues. For this analysis, it was assumed that receipts and issues account for somewhere between 60% to 90% of total NLD workload. Receipts at DSD and NLD account for 38% of total receipt and issue workload (see Table 11).

Table 12 shows the percentage of total NLD workload accounted for by receipts and issues when the range of 60% to 90% is used.

TABLE 12

ESTIMATED PERCENT OF RECEIPTS AND ISSUES TO TOTAL NLD WORKLOAD

| Category | Low Estimate | High Estimate |
|---|---|---|
| Receipts | 23% | 34% |
| Issues | 37% | 56% |
| Total | 60% | 90% |

To determine the effect on total NLD workload, the receipt percentages in Table 12 are multiplied by the estimated 17% increase in receipts at NLD, and the issue percentages in Table 12 are multiplied by the estimated 20% increase in issues at NLD. The results are shown in Table 13.

---

[1] 6,700 receipts of networks spares x 5% commonality = 335
6,600 receipts of other items x 30% commonality = 1,980
Total DSD receipts of items common to NLD 2,315

TABLE 13

EFFECT OF CONSOLIDATION ON NLD WORKLOAD AND COSTS

| Category | Low Estimate | High Estimate |
|---|---|---|
| Receipts (17% increase) | 4% | 6% |
| Issues (20% increase) | 7% | 11% |
| Total | 11% | 17% |
| NLD Cost Increase | $275,000 | $425,000 |

The estimated cost increase at NLD to handle the consolidated workload is shown in the bottom of Table 13. It ranges from $275,000 to $425,000 and was derived by multiplying the total NLD operating cost of $2.5 million by the range of estimates of increased workload (11% and 17%, respectively).[1]

The reduction in annual operating cost by depot consolidation "as is" is estimated in Table 14.

TABLE 14

OPERATING COST REDUCTION BY CONSOLIDATION "AS IS"

| Category | Low Estimate | High Estimate |
|---|---|---|
| Disestablishment of DSD | $633,000 | $633,000 |
| Increase in NLD Costs | -425,000 | -275,000 |
| Net Operating Cost Reduction | $208,000 | $358,000 |

[1]Table 2 shows the cost at $2.7 million. About $200,000 of that amount is for facilities leasing and utilities which will not be affected by workload changes.

There would be a negligible increase in transportation cost, estimated at no more than $5,000.[1] In addition, the one-time costs to effect the consolidation are estimated at $100,000 later in this section. Consolidation would make available the $117,000 in DSD equipment which could be transferred to NLD or other NASA activities or sold.

2. Consolidation with Changed Order Quantity Rule

The maximum potential benefit to NASA arises from a combination of consolidating the two depots and changing the present order quantity rule to an economic order quantity. While benefits could be realized simply through use of an economic order quantity by each system, that is, STDN and DSN, an added increment of benefit from the EOQ effect is achieved only from consolidation.

Both networks use an order quantity of 12 months supply for the depots. DSD and NLD require their supported sites to use an order quantity of 6 months and 3 months supply, respectively. The rules, based upon a fixed number of days supply

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[1]Transportation costs for shipping material to sites from the depots were excluded throughout this analysis. During the 10-month period ending 31 October 1972, DSD shipped 114,522 pounds to West Coast or Pacific Ocean locations and 67,733 pounds to East Coast and Atlantic Ocean locations. Therefore, if all present DSD shipments were made by NLD, 46,789 pounds more would have to be shipped across-country, in a 10-month period, or 56,150 pounds in a year. At a current NLD average shipping cost per pound by truck of 9.8¢, total additional shipping cost per year would be about $5,500. However, this figure should be reduced by savings in consolidation of shipments to the same locations, less packing effort, some lower transportation costs because of reduced rates on larger shipments, and fewer shipments because of fewer issues. The net difference in transportation costs is considered negligible. Order and ship time would have to be increased on items formerly stocked at DSD which would be shipped from NLD to West Coast and Pacific sites.

for all items, cause an unnecessarily high total operating cost because they do not optimize the economic trade-off between the cost to order and the cost to hold material. Use of the Wilson Economic Order Quantity (EOQ) formula would provide significant savings in operating costs to the depots and to the sites.[1]

Two separate benefits can be obtained from use of EOQ at:

(1) Each individual depot and site

(2) A consolidated depot

Table 15 shows the effect of using an EOQ at individual depots and at a consolidated depot (NLD). The table illustrates two cases: Case 1 is a low dollar value of annual demand, and Case 2 is a high dollar value of annual demand. It is assumed that the demand for a common item is three times larger at NLD than at DSD. Under the present rule, NLD and DSD order an amount equal to one year's demand. Therefore, annual demand shown in the "Present Rule" section of the table also represents order quantity.

The "EOQ Rule" section of the table shows the amount which would be ordered under the proposed rule. For the low dollar demand item in the example (Case 1), DSD would order four times more than the present rule prescribes ($20 instead of $5). NLD would order slightly more than twice as much as before ($34 compared to $15). Under the present rule, two requisitions per year would be placed (one at each depot). Under the EOQ rule, the number of requisitions would decrease to 0.69 (0.25 and 0.44 at DSD and NLD, respectively).

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[1]The formula is $Q = \sqrt{\frac{2DA}{HV}}$

where: D = annual demand
A = cost to order
H = holding cost per unit item
V = unit price

In this study, A = \$10, H = .25, and $Q = 8.9\sqrt{\frac{D}{V}}$

TABLE 15

ILLUSTRATION OF EFFECT OF USING EOQ

| | Value of Order Quantity | | | | Number of Requisitions Per Year | | | |
|---|---|---|---|---|---|---|---|---|
| | Individual Depots | | Consolidated Depot | | Individual Depots | | Consolidated Depot | |
| | Present Rule | EOQ Rule | Present Rule | EOQ Rule | Present Rule | EOQ Rule | Present Rule | EOQ Rule |
| Case 1 | | | | | | | | |
| DSD | $ 5 | $20 | | | 1 | .25 | | |
| NLD | 15 | 34 | $20 | $40 | 1 | .44 | 1 | .50 |
| Total | $20 | $54 | $20 | $40 | 2 | .69 | 1 | .50 |
| Case 2 | | | | | | | | |
| DSD | $ 250 | $141 | | | 1 | 1.77 | | |
| NLD | 750 | 244 | $1,000 | $281 | 1 | 3.07 | 1 | 3.56 |
| Total | $1,000 | $385 | $1,000 | $281 | 2 | 4.84 | 1 | 3.56 |
| Total Inv.* | $1,400 | $1,465 | $1,400 | $1,081 | 42 | 19 | 21 | 14 |
| % Change from Present | -0- | 4% | -0- | -23% | -0- | -55% | -50% | -67% |
| % Change from EOQ at Indiv. Depots | | | | -27% | | | | -27% |

*Simulation of total inventory, assuming there are 20 orders for low dollar demand items for each order for high dollar items. Figures obtained by adding 20 x Case 1 Total to Case 2 Total.

For the high dollar demand item (Case 2), the situation would be reversed. The EOQ rule would require smaller dollar value purchases to be made more frequently. For example, NLD would order $244 instead of the present $750, but would order 3.07 times per year instead of once per year.

Where there is a consolidation of two activities which use EOQ, an additional benefit is gained. The number of requisitions per year and the value of inventory of the common items decrease substantially. Table 15 shows that in Case 1, the value of the EOQ would decrease from $54 to $40 with consolidation. The number of requisitions would decrease from 0.69 to 0.50. For Case 2, the value would decrease from $385 to $281 and the number of requisitions from 4.84 to 3.56. The percentage decrease is 27% in each of the four instances.

The bottom half of Table 15 simulates a total inventory. The ratio of about 20 low dollar demand items for each high dollar demand item at NLD was applied to the data in the top half of the table. In this illustration, EOQ with consolidation would lower the inventory value and the number of replenishment requisitions by 27% compared to EOQ at individual depots. Compared to the present rule at individual depots, a consolidation with EOQ would lower the inventory value by 23% and the number of requisitions by 67%.

The amount of reduction in inventory value and number of requisitions when two activities using EOQ consolidate depends upon the ratio of demands for each common item at the two merged activities. Table 16 gives the percentage reduction in the combined number of requisitions and the combined order quantity value for various demand ratios, ranging from the same demand at both depots (n = 1) to 10 times the demand at the larger depot (n = 10). It appears that NLD has about three times more demands than DSD (n = 3), which indicates that an additional 27% reduction in inventory and in receipt workload on common items might be achieved through consolidation of depots.

To determine the potential savings from use of an EOQ at individual depots, LMI calculated the effect on a random sample of 300 NLD stocked items with recurring demand. Using a cost to order of $10 and a cost to hold of 25% of the price of the item,[1] there would be a reduction of 45% in the number of replenishment

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[1] These are the approximate average costs for the network depots. The ordering cost of $10 for NLD can be approximated by dividing the $700,000 annual operating cost for receiving operations ($2.5 million total cost times 28% (average of low and high estimates of receipts share of workload)) by the 66,000 receipts during the year ended 30 September 1972. The holding cost of 25% was estimated as 5% for storage and record keeping, 10% for obsolescence and deterioration, and 10% opportunity cost (interest).

TABLE 16

CONSOLIDATION BENEFIT FACTOR

| Ratio of NLD to DSD Demands n | Percent Reduction in Number of Replenishments & Inventory Value |
|---|---|
| 1 | 29 |
| 2 | 28 |
| 3 | 27 |
| 4 | 26 |
| . | . |
| . | . |
| . | . |
| 10 | 20 |

The benefit is computed from the model,

$$1 = \frac{\sqrt{1 + n}}{1 + \sqrt{n}}$$

The model is derived in Appendix C.

requisitions submitted by the depot. The reduction would occur because lower cost items would be ordered in more than one year's quantity, thus less frequently than at present; higher cost items, which are few in number, would be ordered more frequently. The workload reduction would be achieved with no change in the total inventory value. With a consolidated depot, there would be an additional reduction of about 27% of the combined inventory and number of requisitions for items common to NLD and DSD.

Table 17 shows the effect of consolidation with EOQ on receipts workload. There would be an overall 34% receipts reduction compared to workload in both systems now, and NLD would have a 21% reduction even after taking on the DSD workload.

TABLE 17

EFFECT OF CONSOLIDATION AND EOQ ON RECEIPTS WORKLOAD LINE ITEMS

| | NLD | DSD | TOTAL |
|---|---|---|---|
| Present Situation | 66,000 | 13,300 | 79,300 |
| After Consolidation | 52,300 | 0 | 52,300 |
| Reduction | 13,700 | 13,300 | 27,000 |
| % Reduction | 21% | 100% | 34% |

The figures are derived by multiplying the present NLD receipts by 70% (percent of receipts for recurring demand items) and 45% (EOQ reduction); and by multiplying the DSD receipts by 83% (percent of receipts for recurring demand items) and 45%. The reduced sum of NLD and DSD receipts is then further reduced by the consolidation benefit of 1,250 receipts (2,315 receipts on items common to NLD and DSD x 27% consolidation factor x 2 (demand consolidation factor)).

Use of EOQ at sites could produce a considerable reduction in replenishment orders at sites because the order quantity for DSD sites now is 6 months and for NLD sites is 3 months--which means that, given the same demand for an item, DSD sites now order twice as often and NLD sites order four times as often as the depots. Based upon optimum ordering rules, the order quantity goes up as the square root of demand. Therefore, only when the DSD has four times and NLD has 16 times the demand of a site would the current rules be correct.

Assuming that replenishment workload at sites could be reduced by the same amount (45%) as at the depots, another important benefit would result for the depots, as well as for the sites. Site replenishment orders become depot issues. Therefore, depot issues to sites (excluding engineering changes, provisioning, and other non-routine supply actions) would decrease by 45%. During the year ended 30 September 1972, 71% of the 109,000 NLD issues resulted from site requisitions. Thus, there is a potential annual reduction in issue workload of 32% (71% x 45%) at each depot. Table 18 shows the effect on issue workload by use of EOQ at sites. There would be the same effect with or without consolidation. With consolidation, NLD would have 19% less issue workload than at present.

TABLE 18

EFFECT OF CONSOLIDATION AND EOQ ON ISSUE WORKLOAD LINE ITEMS

| | NLD | DSD | TOTAL |
|---|---|---|---|
| Present Situation | 109,000 | 21,400 | 130,400 |
| After Consolidation | 88,700 | 0 | 88,700 |
| Reduction | 20,300 | 21,400 | 41,700 |
| % Reduction | 19% | 100% | 32% |

Another benefit would result from the use of EOQ. Stockouts would occur about 45% less often because, on the average, the reorder point would be reached 45% less often. Of the 300 item samples from NLD, 14% had a zero balance. Changing to an EOQ calculation would lower the zero balances to about 8% (14% x 55%). This, in turn, would raise supply effectiveness--probably by several percentage points. More precise estimates could be made through computer simulation.

The reduction in operating cost at NLD resulting from a consolidation, with EOQ, is summarized in Table 19. The percentage shares of receipts and issues to total NLD workload, used in Table 12, are applied to the 21% reduction in NLD receipts and 19% reduction in NLD issues.

TABLE 19

OPERATING COST REDUCTION BY CONSOLIDATION WITH EOQ

| Category | Low Estimate | High Estimate |
|---|---|---|
| Disestablishment of DSD | $ 633,000 | $ 633,000 |
| Decrease in NLD Cost: | | |
| Receipts Reduction | 121,000 | 179,000 |
| Issues Reduction | 176,000 | 266,000 |
| Total Operating Cost Reduction | $ 930,000 | $1,078,000 |

The reduction in annual operating cost would range from $930,000 to $1,078,000. In addition, there would be a one-time reduction in inventory of $275,000.[1]

[1] The reduction is calculated as follows: $508,000 of DSD inventory is common to NLD (5% of the $5 million in network spares plus 30% of the $860,000 inventory in other stocked items). $508,000 times the 27% consolidation factor times 2 (the demand consolidation factor which is the square root of the sum of the demand ratios or $\sqrt{3 + 1} = 2$) = $275,000.

The estimated savings if there were a consolidation "as is" (using present order quantity rules) ranged from $208,000 to $358,000. Consolidation with EOQ is the superior approach since it would save an additional $572,000 ($932,000 - $358,000) to $870,000 ($1,078,000 - $208,000) in annual operating cost plus a one-time inventory reduction of $275,000.

The savings by disestablishing DSD would begin immediately after the consolidation is completed. However, the savings from receipt workload reduction would begin a year after initial implementation of EOQ at depots, and the savings in issue workload would begin three months after initial implementation of EOQ at sites.

Section IV discusses in further detail some of the techniques for applying EOQ and calculates the benefit from using EOQ without a depot consolidation.

3. Method and Cost for Consolidation

The cost of consolidating the two depots in one location is sensitive to the method used in carrying out the move. Two general categories of cost will be incurred. The first category is the physical move, including picking, packing, trucking, unpacking, and shelving. The second category includes such cost as planning, merging catalogs, incorporating the DSN inventory data in the STDN inventory management system with all the attendant headaches and difficulties inherent in going from one computer to a different one, training and indoctrination of site personnel to requisition using the STDN standard format, and increased expediting action during the period of the move.

First, in a. following, we suggest what appears to us as a feasible top-level outline of a phased consolidation. An estimate of the cost of carrying out the move is presented in b.

a. Suggested Method

The steps suggested for effecting the move are outlined in the following. The method keeps the DSD operating in an issue-only mode until 30 June 1973.

Step 1: Plan. The consolidation must be a jointly-planned effort by GSFC and JPL. LMI suggests a project approach to the consolidation with a Project Manager being designated from NASA Headquarters.

Step 2: Take up all DSN inventory data in the STDN inventory management system. This would include incorporating historical demand data so that the push system for DSN could be sustained.

Step 3: Direct all sites to requisition on NLD using NASA Communications System (NASCOM) and the STDN standard formatted line item requisition procedure.

Step 4: NLD direct DSD to make shipments as required to sustain network support. All items common to both networks to be shipped to the Pacific area would be issued out of DSD to both DSN and STDN sites. Common items for the Atlantic/ European area would be shipped by NLD to both networks. Peculiar items would be shipped from the holding depot.

Step 5: NLD make all replenishment procurements, using EOQ, effective on the date that requisitions start to flow to NLD. All purchased material to be received at NLD (or shipped direct to sites).

Step 6: As of 30 June, close DSD.

Shipment of material from DSD to NLD should be taking place during the four months prior to closing DSD. The shipping sequence, by category of material is shown in Table 20.

TABLE 20

MATERIAL SHIPPING SEQUENCE

| Items Common to NLD & DSD | | Items Peculiar to DSD | |
|---|---|---|---|
| Recurring<br>4 | Non-Recurring<br>2 | Recurring<br>3 | Non-Recurring<br>1 |
| ON 30 JUN | MAY | JUNE | MAR-APR |

The first material to be shipped should be peculiar non-recurring, 1 in the table. The second should be common non-recurring, 2 in the table. Shipping in that order will allow for maximum issues from DSD prior to 30 June and minimize the total amount of material to be shipped from DSD to NLD. The stock of peculiar recurring could be split into two shipments, one the first of June and the second about mid-June, in order to assure access to stock at all times.

There are many other actions that must be taking place throughout the steps mentioned above. DSD should cease all standardization and catalog action and divert those personnel to identifying and disposing of excess material in the warehouse. Soon after NLD assumes responsibility for purchasing, some DSD personnel engaged in receiving can be diverted to readying and shipping peculiar non-recurring items. As receipt workload and issue activity falls off at DSD, more and more personnel will become available for diversion to effecting the move. These, though, are details for planning. LMI believes the JPL effort required for physical consolidation, if phased as outlined above, can be made with the personnel onboard at DSD.

The above list and comments on other actions are in no way complete. They are offered to portray one concept of how the consolidation can be carried out.

b. Estimated Cost of Consolidation

(1) Packing at DSD. All purchasing would cease and receiving activities would begin to diminish at DSD at the beginning of the consolidation program. As a result, additional manpower will be available to pack material for shipment to NLD without an increase at DSD in out-of-pocket labor costs. In fact, during the last two or three months, there is the possibility of terminating 10 to 20 personnel because of reduced workload. There would be a small cost of perhaps $2,000 for packing materials.

(2) Shipping. It is estimated that about 325,000 pounds of material would have to be shipped from DSD to NLD. At an average cost per pound by truck of 9.8¢, the cost should be about $32,000.

(3) Unpacking and Reshelving at NLD. Assuming all 21,500 items are shipped and that it takes 10 minutes to handle each line item, three men could handle the workload over the four-month period (March-June). Because of current NLD workload, it seems likely that three additional personnel would have to be hired for the period. At a cost of $8,000 per man, the total cost would be $8,000 ($8,000 x 3 people x 1/3 year).

(4) Computer Costs. Computer programs must be adjusted to take up the DSD data and to assume the task of directing shipments for several months from two warehouse locations. Software effort is estimated at $25,000. Computer time to take up the additional 24% of line items and 33% one-time receiving is estimated to increase computer costs about 25% for a six-month period. Computer costs are running $22,000 per month. The additional computer cost should be no more than $30,000 ($22,000/month x 6 months x 25% increase).

(5) Increased Receiving and Issuing Workload at NLD. For the first three months of operation, assuming EOQ is implemented at the same time as the consolidation is effected, issue workload will increase about 20%. Then it will decrease by 19% from current levels. Receipts workload will increase by 17% for the first year and then decrease by 21% from current levels. NLD should be able to handle the temporarily increased workload with the 200 people authorized in the new contract. As workload decreases, we believe the work force can be reduced substantially, probably within two years.

The total one-time, out-of-pocket costs for the consolidation, as itemized above, are estimated at about $100,000.

4. Other Potential Benefits

In Section IV a number of changes for improving the individual systems are offered without regard to the question of consolidation. There are some potential benefits to be gained that are unique to consolidation in addition to those already mentioned in this section. We only highlight them here--it either is impossible to quantify them, or time was not available. Such benefits include:

- With an increase in safety level at the consolidated depot, stockouts would become fewer, and supply effectiveness would increase correspondingly.
- More intensive effort could be placed on research and cataloging the thousands of items now carried with only manufacturer's part numbers or pseudo-part numbers. All technical documentation on such items would be centralized at one depot. The result would be increased identification of common items and improved material control and more uniform routine processing actions.
- With a combined issue activity, more items would become recurring and would be stocked, thus ensuring faster response time in providing those items to sites.
- Better utilization could be made of long supply items at one site by transferring them to requiring sites anywhere in the system.
- With one consolidated depot, NASA would be better able to manage the overall logistics support for its networks.

## C. CONSOLIDATION AT SITES

LMI visited tracking stations at two locations--Rosman, North Carolina, and Goldstone, California. Rosman has only one station and one supply department; therefore, consolidation there is not an issue.

The supply support operations at Goldstone are depicted in Figure 1. Store 91 handles technical material (S-Band); Store 92 handles general supplies. The two stores provide support to all DSN activities at Goldstone. They are located within one warehouse; in fact, the supplies are commingled, and are under the same management. The stores are resupplied daily by truck from the DSD. JPL-supplied items for Store 92 move on the same truck. In addition, the Network Maintenance Complex is supported on a daily basis, by truck, directly from DSD on items not stocked at Store 91.

Each of the STDN sites operates independently; however, they do have local ad hoc arrangements for mutual support. They go individually to the open market for local purchase. Local purchase as used here means that items are purchased by the stations--not necessarily in the local area. The purchases are placed with vendors and manufacturers throughout the United States.

The line items carried and inventory value of Goldstone activities are shown in Table 21.

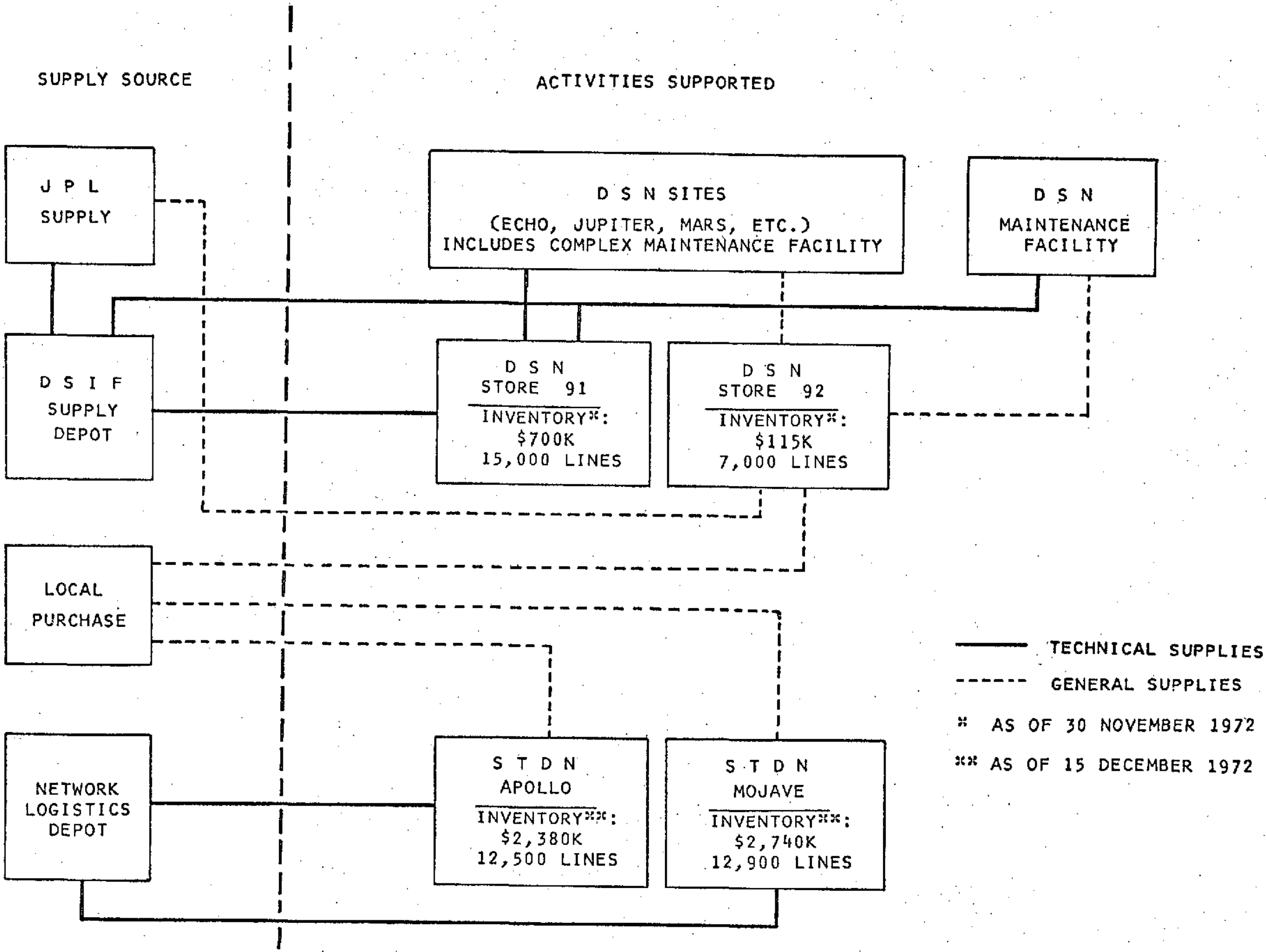


FIGURE 1: GOLDSTONE SUPPLY SUPPORT SYSTEMS

TABLE 21

INVENTORY AT GOLDSTONE
As of 31 October 1972

| Station | Line Items | Value |
|---|---|---|
| Apollo | 12,500 | $2,380,000 |
| Mojave | 12,900 | 2,740,000 |
| Echo: | | |
| DSS 91 | 15,000 | 700,000 |
| DSS 92 | 7,000 | 115,000 |
| Total | 47,400 | $5,935,000 |

LMI made no detailed evaluation of the redundant effort and inventory at Goldstone. It has to be there--it is common to any such decentralized and independent supply support operations within a limited geographical area. We are confident that a detailed study would reveal such conditions as: (1) one activity purchasing items in long supply at another, (2) all activities buying identical items for the same functional purpose, at different times and at different prices, (3) commonality in items stocked, and (4) more persons engaged in the function than would be required under a consolidated system.

It is recommended that supply support at Goldstone be centralized--that one activity, one manager--be given total supply support responsibility for all NASA activities located there. The centralized support for the DSN sites works. It will work equally well for all sites.

It is recognized that warehouse space may not be available for a single warehousing location. It was noted that many structures at Goldstone are the "Butler" variety, which can be moved with only partial disassembly. An alternative is to stock only certain types of items, for example popular or recurring demand items, in one existing warehouse, and the remaining types, for example, slow moving and insurance items, in another warehouse at the Goldstone complex.

Our recommendations on site consolidation are directed only to the site we visited, Goldstone. However, to the extent conditions are similar at overseas locations, particularly Australia, Spain and South Africa, there exists a basis for serious consideration of consolidated supply support at those locations. Consolidated support consideration should not be limited to those locations where STDN and DSN are co-located. The arguments for it are applicable to locations where either network alone has multiple sites. It is recognized that NASA's agreements with the host governments of overseas locations may influence to a considerable extent what can be done to inject more discipline and control into station supply operations. It appears to LMI to be worth a try.

# IV. POTENTIAL IMPROVEMENTS IN INDIVIDUAL SYSTEMS

## A. INTRODUCTION

The secondary purpose of the LMI task was to identify improvements which could be made in either or both supply systems regardless of whether there is a consolidation of depots. This section presents a number of potential improvements. The improvements would reduce operating costs and increase supply effectiveness. They can be implemented singly or in any combination, and are independent of benefits to be realized from the consolidation of depot facilities. However, implementation of the recommendations in this section, together with a consolidation of depots, would result in the maximum benefit to NASA.

Improvements are described under the following categories: (1) determination of stock level requirements, (2) initial provisioning, (3) handling of long supply, (4) supply effectiveness, (5) services to sites, and (6) other workload savings.

## B. DETERMINATION OF STOCK LEVEL REQUIREMENTS

The stock control level used by NLD and DSD, called requisitioning objective (RO) in this report, consists of the sum of three elements: safety level (SL), order and shipping time (OST), and operating level or order quantity (Q). Changing the order quantity calculation offers the best opportunity for reduction of operating cost. Changes in safety level and order and ship time will improve supply effectiveness with perhaps small savings in operating cost.

1. Operating Level (Order Quantity)

Economic order quantity was discussed in Section III. EOQ can be easily implemented regardless of whether there is a depot consolidation, and the benefits without consolidation would range from $584,000 to $874,000 reduction in annual operating costs at NLD and DSD. Table 21 summarizes the derivation of the cost reduction, using the same approach as in Section III. The percentages for the receipts and issues share of total workload (low and high estimate) are taken from Table 12. Relevant total operating costs at NLD and DSD are considered to be $2.5 million and $521,000 ($633,000 less $112,000 in facilities costs), respectively. For NLD receipts, the calculation is $2.5 million times 45% EOQ reduction times 70% recurring demand receipts times Table 12 receipt percentage. For NLD issues, the calculation is $2.5 million times 45% times 71% recurring demand requisitions from sites times Table 12 issue percentages. For DSD receipts, the calculation is $521,000 times 45% times 83% times Table 12 receipt percentages. For DSD issues, the calculation is $521,000 times 45% times 71% times Table 12 issue percentages.

TABLE 22

EFFECT OF EOQ ON INDIVIDUAL DEPOTS

| Category | NLD | | DSD | | Total | |
|---|---|---|---|---|---|---|
| | Low Estimate | High Estimate | Low Estimate | High Estimate | Low Estimate | High Estimate |
| Decrease in Receipts Workload | $181,000 | $268,000 | $45,000 | $66,000 | $226,000 | $334,000 |
| Decrease in Issue Workload | 296,000 | 447,000 | 62,000 | 93,000 | 358,000 | 540,000 |
| Total Reduction in Operating Cost | $477,000 | $715,000 | $107,000 | $159,000 | $584,000 | $874,000 |

There would be a corresponding savings at each site ranging from 7% to 13% of total operating costs.[1] Operating costs for individual sites were not determined. In addition, stockouts would decrease, supply effectiveness would increase and there is a good likelihood that inventory dollars would decrease.

The change-over to use of EOQ would be simple. It would require substituting the term $Q = 8.9\sqrt{\frac{D}{V}}$ for the present term Q = D in computer programs. Where manual computations are made at sites, a simple "look-up" table can be prepared. For shelf life items, order quantities should be limited to demand during shelf life less the safety level quantity.

Items with less than $80 in annual demands would be ordered in quantities greater than a one year's supply. For example, an item with a $25 annual demand would be ordered every 1.8 years, and an item with $1 annual demand would be ordered every 8.9 years. In those instances where a several year's supply is indicated, the program planning horizon should be reviewed to ensure that there is a high likelihood that the item will not become obsolete during the holding period. If the program or equipment to which the item is applicable is being phased out, the order quantity should be reduced accordingly. Where there is an increasing or decreasing demand for

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[1] The reduction would range as follows:
Low: 45% EOQ savings x 70% recurring demands x 23% receipts share of total workload
High: 45% x 83% x 34%.

an item, the changes in demand should be taken account of. A simple and effective method of forecasting demand based on historical demand data is the exponential smoothing model.[1]

It should be noted that use of the EOQ formula permits managers to trade off inventory and workload. For example, should there be a funding limitation which requires a reduction in inventory investment, the formula can reduce inventory levels in an optimum manner. All that is required is to lower the K factor[2] by the appropriate amount, and the order quantities for all items are lowered by the percent decrease between the old and new K factors.

The workload benefits from using EOQ at the depots would begin to be realized one year after implementation. This is because the depots are currently ordering a one year supply. Based upon the LMI sample, the depots would be ordering a longer supply for the majority of items when using EOQ. Therefore, it would take one year for the change to be noticed. During the first year of using EOQ, requisition workload would increase slightly, perhaps about 5%, because higher dollar items would be ordered more frequently than the present once a year. This will produce a lower inventory investment for the first year.

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[1]One of the better books describing the model is <u>Time Series Analysis Forecasting and Control</u> by George E. P. Box and G. M. Jenkins (San Francisco: Holden-Day, 1971).

[2]The K factor in the EOQ formula is

$\sqrt{\frac{2A}{H}}$ or about 8.9 in the analysis in this study, where A = cost to order of $10 and H = holding cost of .25 unit price.

During the second and third year, as stability is reached under the new system, inventory investment should return to about the present levels and workload on recurring demand items should stabilize at about 45% of the present level. Use of EOQ at sites would begin affecting NLD in three months and DSD in six months because present rules call for NLD and DSD sites to order three months' and six months' supply, respectively.

2. Safety Level (SL)

The present depot rules prescribe that the safety level (SL) is a fixed number of days supply for specified items--usually one or two months. Such rules defeat the purpose of SL, which is to ensure that the depot can meet a specified percent (e.g., 95%) of all demands for the item. A fixed number of days supply for all items cannot take account of the variability of demand for each individual item. As a result, variable protection is provided on items, and there are more stock-outs per dollar inventory investment using the present SL than would be the case if SL were based upon probability of stock-out for individual items. The principle is somewhat similar to EOQ, discussed earlier.

LMI recommends that depots and sites calculate safety level for each individual item by use of the formula $C\sigma$, where $\sigma$ is the standard deviation of demand over the lead time, and C is the number which specifies the desired probability of having the item in stock (the number of standard deviations of protection desired)--a C of 2 would provide about 95% protection, which is the initial figure LMI recommends be used.

LMI could not estimate the benefits from changing to the proposed SL rule because sufficient demand information was not readily available to us at either NLD or DSD. However, use of the proposed SL rule will significantly lower stock-outs (found to be 14% of recurring items in the LMI sample described earlier) and improve supply effectiveness (which, at about 91% in September, 1972, is considered too low by LMI).

The SL rule is simple to use in computer programs, provided data on the number of individual demands and total demands are available. The SL rule should be applied to all items.

3. Order and Ship Time (OST)

Both networks use the correct method to determine OST. However, DSD generally uses a single fixed number of days (for example, 90 days) to represent the average number of days for OST for all items in inventory at overseas sites and another fixed number of days for sites within the U. S. More precise determination of OST for each individual item carried or at least for similar categories of items would produce higher supply availability at the same or lower cost. Where shipping time can be reduced, a one-time inventory saving is achieved equal to the ratio of the new OST to the former OST times the dollar value of the former OST.

C. INITIAL PROVISIONING

Much of the inventory on hand at NLD and DSD was initially provisioned to meet anticipated demands, but has not been required for years. At NLD, for example, 33,625 of the 67,840, or 50% of the line items as of September 30, 1972, had not been issued in one year or more. The inactive stock represented $15,484,000 of the $22,409,000 inventory on hand, or 69%. As of December 15, 1972, the figures were $17,464,000 inactive stock out of a total inventory of $22,263,000, or 78%.

At DSD on September 30, 1972, there were 5,269 line items out of 17,000 (excluding network spares for which data were not available), or 69% with no issues during the preceding nine months or more. (Data for a longer period were not available; DSD plans to make an analysis soon covering a period of 21 months.) The dollar value of DSD stock material inventory which has not been issued for one year or more could not be obtained. An approximation can be made by comparing the stock material inventory value of $866,000 on hand at DSD as of September 30, 1972 with total issues of stocked items for the year ending September 30, 1972, of $476,000. Since the present order quantity is one year, it would be expected that, if there were no inactive stock, issues should exceed on hand stock by about 50%.[1] Therefore, the dollar amount of inactive stock at DSD can be estimated as 63%[2] of the total on hand value. The percentage may be closer to 69% (the line item percentage) because many items have multiple demands during the year and inactive stock (insurance and critical items included) generally has a higher dollar value than the average value of total inventory. Therefore, the amount of inactive stock would be about $598,000.[3] If the same percentages apply to DSD network spares, the applicable DSD inactive stock of network spares would be $3,450,000.[4]

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[1] Average quantity on hand = safety level of two months + 1/2 order quantity of 12 months = 8 months. 12 months is 150% of 8 months.

[2] $100\% - \left(\frac{\$476,000}{\$866,000}\right) 150\% = 63\%.$

[3] $866,000 x 69% = $598,000.

[4] $5,000,000 x 69% = $3,450,000.

For all DSD sites combined, the comparable figures are 13,442 line items out of 42,440, or 69%, with no issues in one year or more. Inventory at those sites was $1,450,000 on September 30, 1972, indicating that the value of inactive stock at the sites was about $1,000,000. Data on inactive stock were not obtained for NLD sites, but personnel at Rosman and Goldstone stated that it was at least 70%. Material on hand at all NLD sites combined was $44 million on December 15, 1972.

Improvement in techniques for determining initial provisioning requirements could provide large savings to NASA. NLD and GSFC purchased $2.5 million of initial provisioning material during the period May, 1971 - December, 1972 (records were not maintained in readily available format before May, 1971), or $1.5 million per year. At present, about 69% of inventory is inactive. More precise provisioning might reduce by half that 69% inactive stock. The savings could come to more than $500,000 annually at NLD in the purchase of new material ($1.5 million x 69% x 50%). Operating costs would be lower because of reduced warehousing workload, physical inventory workload, and ADP time.

A certain amount of material must be held as insurance items at sites or depots because of insufficient acquisition lead time or because the material might be out of production and would not be available from vendors. However, it appears that NASA has an unnecessarily large inventory of inactive stock. The situation indicates, among other things, that initial provisioning procedures may need to be refined.

LMI offers the following suggestions as beginning steps to improving the initial provisioning procedures.

1. <u>Determining Requirements</u>

a. Initial provisioning is a complex operation that requires several kinds of expertise. Design and development engineers are needed to provide insight into probable failure rates, operating engineers are needed to modify estimates based upon knowledge of the applicable operating environment, supply personnel must bring to the provisioning effort information about the existing capability to support the equipment to be provisioned, and logistics personnel are needed to interpret all factors and determine the range and depth to be provisioned and where the provisioned items should be located. The overall objective is to minimize support costs for a specified level of availability. There is evidence that direct high level attention has been given to the provisioning function in recent months at both GSFC and JPL. A JPL draft document, specifying new initial provisioning procedures, was reviewed. It should be implemented. Both JPL and GSFC should continue to refine the provisioning process.

b. There appears to be no feedback to provisioners as to how accurate were their estimates. It would be useful to analyze actual item usage by equipment at some fixed period after the items are provisioned and to provide the information to provisioners so they might adjust their estimates or techniques in the future.

c. We observed instances where the quantity of each provisioned item for a specific site is determined by multiplying the number of equipments to be supported by the provisioning quantity for one equipment. It does not normally require twice as many spare parts to support two identical items of equipment as it does to support one item. Adjustments downward should be made in the total quantity when more than one item of equipment is to be supported.

2. Obtaining and Positioning Material

At NLD, after provisioning requirements for each site are calculated, assets on hand at the site are considered, and where deficits exist, the appropriate quantity is shipped from NLD or ordered from the manufacturer. Long supply at another site is not transferred to the requiring site. In view of the large amount of dead stock in the system, such long supply should be used where possible to fill provisioning requirements.

D. HANDLING OF LONG SUPPLY

Some of the inactive stock discussed above can be considered important to retain because of the difficulty or impossibility of replacing it, the criticality of the material to NASA's missions, or other good reasons. However, much of the inactive stock is in long supply or excess to needs of either the depots or NASA. In the 300 item sample of NLD's inventory, described earlier, LMI found 41% of the recurring demand items were in long supply (the quantity on hand was larger than the requisitioning objective). With more than $22,000,000 in inactive stock in the system, possibly as much as $10,000,000 is not needed.

Holding unnecessary material increases operating costs. At some point, it costs more to hold inactive stock than to dispose of it and repurchase it later, if necessary. Management of long supply at depots seems to be a hit or miss operation which has not been effective. NLD has placed more emphasis in this area in FY 1972, transferring, selling, or disposing of $574,416, compared to $164,367 in FY 1971. However, more aggressive screening and disposal action at NLD and DSD would pay off.

Two formal rules were found at DSD concerning management of long supply at sites. The rules are (1) sites are to return to DSD material which is more than 150% of the stockage objective of 6 months, or all material greater than 9 months' supply; and (2) where there are no issues of the item during the past year, all material above the safety level is to be returned. The rules are not being followed, as can be noted from data presented earlier. However, if the rules were enforced, they would not necessarily produce optimum or even desirable results. The result could be larger transportation and handling costs than the benefits derived from moving the material.

LMI recommends that OTDA establish the following three rules for handling long supply. The rules maximize the net benefits when holding and transportation costs, expected demands, and disposal values are considered.[1]

1. Transfer Level (TL)

TL is defined as the quantity of material on hand above which it is more economical to transfer material to another activity needing it than to hold it, assuming that the full quantity requisitioned can be transferred. Material on hand below TL should not be moved because it is more economical

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[1]Logistics Management Institute, "Economic Retention Levels for Army Supply Activities," LMI Task 70-22, June 1971, AD Number 725872.

to hold it until used than to incur the fixed and variable shipping costs to transfer it to another location.

> TL = Requisitioning Objective = Safety Level + Order and Ship Time + Operating Level (or Order Quantity)

2. <u>Reporting Level (RL)</u>

RL is defined as the level above which stocks on hand above TL should be reported as long supply to the next higher authority.

> RL = 2TL. A minimum value per line item of $50 for U. S. locations and $100 for overseas locations should be set.

3. <u>Economic Retention Level (ERL)</u>

ERL is defined as the level above which stocks on hand should be disposed of by transfer outside NASA, if NASA Headquarters instructs the activity to dispose of the item.

> ERL = Safety Level + Order Quantity + 4 years' supply.

For each of these rules, it is assumed that demand for the item is recomputed at least annually and that stock levels are adjusted accordingly, especially for items associated with equipment or programs being phased out in the near future.

NASA does not redistribute long supply to requiring activities as frequently as it should. As a result, unnecessary new procurements are made. One example of this was given earlier in this study under "Initial Provisioning."

Also, the depots and sites tend to hold inactive stock too long. As discussed earlier, there are about $22 million in long supply in the two network supply systems. Some of this material could be resold to DSA and GSA to recoup funds. For example, as of December 15, 1972, there was $3,424,000 in inventory of DSA/GSA material at NLD, of which $927,000 was for recurring demand items. Some of the non-recurring demand material was initially provisioned within the past year, and sufficient time has not elapsed to determine whether the items will become recurring. However, since only $66,000 in DSA/GSA material was for initial provisioning in FY 1972, it is likely that most of the $2.4 million could be disposed of. There is a potential excess of about $2.4 million. Some of the items might be returned to DSA and GSA for full credit (if within DSA and GSA's stock requirements). As of 31 December 1972, NLD had outstanding 5,676 line items of excess material valued at $1.4 million ($416,000 of federal stock numbered items and $953,000 of non-FSN commercial items) which they had offered the Defense Contract Administration Service (DCAS) but had received no disposal instructions. LMI understands that NLD had located other federal agencies who were willing to accept the excess material. NASA should seek permission from DCAS to dispose of excess material to other federal agencies, where appropriate. Adoption of the three rules above for long supply will result in lower operating costs at depots and sites, as well as a lower investment.

There should be a central coordinating point in the network tracking system to manage long supply. If the two depots are consolidated, the consolidated depot is the appropriate point. Using the proposed rules for managing long supply, the depot periodically should provide sites with listings of items in long supply and instructions on what action to take on each item. The listings, including instructions on disposition, would be an output of the computerized system once the rules were programmed. Sites should be required to follow the instructions except where the site director has an overriding need to deviate on an item by item basis.

## E. SUPPLY EFFECTIVENESS

Supply effectiveness[1] at the depots is not as high as it might be for the same system cost. NLD has established the following supply effectiveness criteria:

85% for stocked (recurring demand items)

95% for "Push" items (selected high demand items at Rosman Station only)

For NLD, data are given in Table 23. Data for DSD were not available.

TABLE 23

NLD SUPPLY EFFECTIVENESS
September 1972

| Requisition Priority | | Supply Effectiveness |
|---|---|---|
| I. | Critical | 79% |
| II. | Emergency | 92% |
| III. | Expedite | 90% |
| IV. | Routine | 92% |
| | Total | 91% |

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[1]Supply effectiveness is the percent of demands for stocked items which can be met within a specified number of days.

LMI believes that the depots could achieve a 95% supply effectiveness for all recurring items with little, if any, increase in operating costs. Processing time could also be shortened. Not only would this provide better supply support to sites, but it would also reduce the sites' order and ship time and the on hand inventory balances at sites, thereby reducing inventory investment.

Supply effectiveness at the depots and sites could be improved by adopting the following four recommendations:

1. Use the proposed new rules, described earlier, for safety level, order and ship time, and order quantity. Safety level should be set at 95% protection against stockouts.

2. Intensify the program of inventory material identification--assigning federal stock numbers to as many items as possible and assigning pseudo stock numbers (PSN) to all part numbers. NLD has increased their efforts under the new contract with Raytheon which began January 1, 1973. DSD, however, has about 10,000 line items identified only by a part number.

3. Modify physical inventory procedures to count recurring items more often rather than at a fixed period of time. Table 24 describes the present physical inventory plan for NLD. DSD is inventorying all items on an annual cyclic basis.

TABLE 24

NLD PHYSICAL INVENTORY PLAN

| Category | Unit Cost of Line Item | Frequency of Inventory | % Accuracy Goal (NLD) |
|---|---|---|---|
| I | $500 or more | Quarterly | 100 % |
| II | $ 25 - $499.99 | Annually* | 95 |
| III | Less than $25 | Tri-Annually* | 92 |

*Sampling of inventory is acceptable

Most issues (85% of all issues at NLD for the period July 1 - September 30, 1972) are for low value items--Cost Category III. Many of those issues are for recurring demands on the same line items. There would be a high payoff to maintaining increased accuracy on those recurring demand items. The current plan to inventory all low value items every three years should be changed. One simple rule might be to inventory all items when their reorder point is reached. This action would ensure that procurements are for the quantity actually needed. In those instances where there is an error in the records, showing that the reorder point has been reached when in fact a larger quantity is on hand (the item might actually be in long supply), an unnecessary procurement would be stopped and inventory investment would be reduced.

4. <u>Monitor more closely high priority items</u>. Studies should be made to determine which recurring demand items are requested on requisition priorities 1 and 2. Intensive efforts should be made to ensure on hand availability of the items. Where necessary, safety levels and order and ship time should be adjusted. Physical inventory should be taken more often for these items, and responsibility should be assigned for controlling them. The list might be expanded to include all recurring demand items, regardless of requisition priority, where annual demands exceed a specified number (for example, all items with five or more demands annually).

## F. SERVICE TO SITES

The depots can provide a number of improved services to network sites. Several of those described here were recommended to LMI by personnel at various sites.

1. Use the push system for routine replenishment from NLD to sites. DSD has a push system for all sites. NLD is experimenting with the idea and is currently testing the concept at its Rosman tracking site. LMI recommends that the push system be used at all sites and for all recurring items. It will eliminate most of the replenishment workload from sites. To make the system work most effectively and with the least workload impact on sites, NLD should obtain actual issue data from sites, as DSD does, and should discontinue the "balance overlay" approach.

2. Obtain site issue data at DSD by teletype through the NASCOM system. NLD receives issue data daily from sites by teletype through NASCOM and can make a daily update of site stock status. DSD has their supported sites use the mails to send in issue data even though DSD uses a push system for site replenishment. Use of the NASCOM system by DSD sites appears to be the better approach.

3. Provide more accurate shipping data. Some sites do not consider the shipping information provided to them to be reliable. LMI was told by some sites that the depots frequently update shipping advice monthly by automatically adding a month to the last reported time. For example, if a January report indicated that an item should be shipped by January 25, then the February report would show the item being shipped by February 25.

4. Provide Inventory Aids. Depots could assist sites by providing bin tags, locator cards, and similar aids when new items are added to the sites' inventory or when stock number changes occur.

5. Validate Due Out Listings. Due out listings are provided to NLD sites monthly and to DSD sites semi-annually. The sites usually do not verify continuing need for the items. Items that have been due out for a long period of time often are no longer needed. Thorough checking of the listing by each site and prompt notification to the depot when items are no longer needed would reduce procurement workload and inventory investment. DSD should provide due out listings quarterly.

## G. OTHER WORKLOAD SAVINGS

1. Transshipment of items needing repair. Repairable items needing repair are shipped to NLD for transshipment to appropriate repair facilities. That procedure entails double handling, increased transportation costs, longer turn-around time, and increased possibility of breakage. LMI recommends that NASA develop procedures for sites to ship items needing repair directly to the appropriate repair facilities.

2. Popularity stowage at NLD Warehouse. NLD is located in two separate, but contiguous, warehouses with personnel stationed in both locations. If NLD stored only items with no demands for the past year or two in the smaller warehouse, it might be possible to keep that warehouse locked most of the time and move the personnel to the main warehouse. Under the proposed stowage plan, issues from the smaller warehouse might not be required for more than a few hours one day a week.

Also, popularity stowage might be used in the main warehouse. Items of the largest recurring demands might be placed in one general area. Such stowage would enable fewer personnel to handle the issue workload. This plan would fit in with the recommendations proposed elsewhere in the report to manage recurring demand items more closely.

## V. POTENTIAL IMMEDIATE ACTIONS TO REDUCE COSTS

### A. BENEFITS IN FY 1973

1. Sell back excess DSA and GSA items. As of 15 December 1972, NLD had $3,434,000 in inventory of those items, of which $927,000 was for recurring demands. Some items have been on hand too short a time to have had recurring demands. There is a potential excess of about $2,400,000. DSA and GSA will accept returns for full credit if the returned material doesn't increase their inventory to over two years' supply.

2. Consolidate and intensify management of long supply. With 69% of stock inactive at both depots and 41% of recurring demand stock in long supply at NLD, there is a high probability that some new procurements can be avoided, possibly $100,000 by June 30.

3. Have NLD buy material for both systems. The study indicates that $275,000 can be saved in inventory. If the material were purchased over an 18-month period, savings from March--June 1973 would amount to $61,000.

4. Refine provisioning procedures and reduce procurements for initial provisioning. With an average annual expenditure at NLD of $1.5 million in new procurements for provisioned items and 69% or more of provisioned items remaining inactive, if only half as much as usual were purchased, the savings from February--June would be $315,000.

5. Implement EOQ at depots and sites immediately. There would be a reduction in issue workload associated with NLD sites

beginning in three months and with DSD sites beginning in six months. The savings at NLD from May-June could amount to $75,000.

B. <u>BENEFITS IN FY 1974</u>

1. Implementation of EOQ at depots and sites in February 1973 would provide annual savings ranging between $584,000 and $874,000 beginning in May 1973 and gradually increasing until about February 1974 when the full potential would begin to be realized.

2. Consolidate DSD into NLD. Implementation cost would be about $100,000. There would be a savings at DSD of about 20 people in FY73 = $40,000 (20 people x 25% yr. x $8,000) and about $200,000 a year beginning in 1974--in addition to the savings in B-1.

# APPENDIX A

CONTRACT NASw 2306
TASK ORDER NASw 73-T

13 November 1972

Pursuant to Articles I and II of the National Aeronautics and Space Administration Contract No. NASw 2306 with the Logistics Management Institute, the Institute (LMI) is requested to undertake the following task:

<u>TITLE</u>

Supply Support of NASA Tracking Networks

<u>SCOPE OF WORK</u>

a. <u>The Problem</u>

The Jet Propulsion Laboratory and the Goddard Space Flight Center each operate an independent supply system: JPL to support the Deep Space Network (DSN) and GSFC to support the Space Flight Tracking and Data Network (STDN). LMI is to review each of the supply systems to determine whether and to what extent the two systems should be merged. The objective is cost reduction; no degradation in supply performance to either network is acceptable.

b. <u>General Approach</u>

LMI will study the two independent supply systems to that level of detail necessary to support a recommendation either to consolidate or to not consolidate. It is expected that this can be done through straightforward and well understood analytical techniques. The supply effectiveness of each system will be determined, perhaps by reference to existing NASA measures currently applied, if any, or by development of a special measure ~~of our own~~. The costs of operating each system will be determined. An estimate of the cost of a combined system then must be made, as well as an estimate of the one-time cost of effecting consolidation. A basis for a general recommendation should emerge from the foregoing.

During the conduct of the above basic study, it is expected that opportunities to improve the existing systems will be identified, and that some opportunities applicable only if the two systems are combined may become evident. In either event, such opportunities will be documented and, if the recommendation is made to combine the systems, the benefits of the latter opportunities will be applied in that portion of the estimate of benefits. It is to be expected that improvement opportunities exist in such areas as stockage levels, disposal rules and procedures, transportation, initial provisioning, EDP support, and communications, in fact, in any area of supply support.

c. Method of Study

Visits will be made to NASA Headquarters (OTDA), GSFC, JPL, contractors' depots (Ownesville, Maryland, and Monrovia, California), and at least two tracking stations (Rosman and Goldstone) to obtain data, analyze present systems, and develop improvements and recommendations.

SCHEDULE AND REPORTS

Work should be completed and a final report submitted by January 26, 1973. Oral briefing shall be presented following the preparation of the final report.

TECHNICAL DIRECTION

The NASA Technical Director for this task will be Mr. William L. Folsom, Office of Tracking and Data Acquisition or his designee.

Thomas G. Mancuso
Special Assistant to the Acting Assistant Administrator
for Industry Affairs and Technology Utilization

APPENDIX B

LIST OF STDN ACTIVITIES

ACN - Ascension

ADE - Adelaide, Australia Switching Center

AGO - Santiago, Chile

ALE - Fairbanks, Alaska, ERTS Designator

BDA - Bermuda Island

BUR - Johannesburg, South Africa

CAL - Calibration Aircraft (RCA)

CSW - Deaking Switching Center, Australia

CYI - Canary Island

DOS - Module Repair Facility and Precision Measurement Lab (BFEC)

ESC - Engineering System Compatibility Facility (MSC)

GDE - Goldstone-Barstow, Cal. ERTS Designator

GDS - Goldstone-Barstow, Cal. (STDN)

GDX - Goldstone-Barstow, Cal. (JPL)

GLN - Glendale Bldg. - NTTF Support of GFE 642B Computer to Univac

GSC - Misc. Requisitions to GSFC

GWM - Guam Island (Marianna Islands)

HAW - Kauai Island, Hawaii

HON - NASCOM Switching Center, Honolulu HAW

HSK - Honeysuckle Creek, Canberra, Australia (STDN)

HSX - Canberra, Australia (JPL)

LDN - London, England, Switching Center

LEC - Material Requirements for Eng. Equip. Modifications

LEI - Material Requirements for Eng. Equip. Modifications

LOG - Misc. Support Materials for Prototype Equipment Modification Kits

MAD - Madrid, Spain (STDN)

MAX - Madrid, Spain (STDN) Designator for STDN Equip. Located at Madrid JPL Site

MEL - Engineering Lab, Bldg. 25, GSFC

MIL - MSF - Marshall Space Flight Center

NFL - St. Johns, Newfoundland

NIA - Bendix Flight Operations - Instrumented Aircraft

NOA - ESSA/Nat. Environmental Satellite Center

NOC - Network Operations Control Center, GSFC

NTF - Network Test and Training Facility, GSFC

PKS - Parkes, Australia, Radio Astronomy Site

PME - Precision Measuring Equip. Lab., BFEC, Columbia, Md.

QUI - Quito, Ecuador

SOC - Projected Oper. Control Center. GSFC

SPP - Spare Parts Provisioning for Network Equip.

STS - NASCOM Switch Center, Greenbelt, Md.

TAN - Tananarive, Malagasy Republic

TEX - Corpus Christi, Texas

TOS - Wallops Station, Va., Nat. Environmental Service

ULA - Fairbanks, Alaska

VAN - U.S.N.S. Vanguard

WNK - Winkfield, Berkshire, England

APPENDIX C

## DERIVATION OF CONSOLIDATION SAVINGS FACTOR

### A. INTRODUCTION

This appendix derives the net benefit obtained when material common to two different warehouses is combined into one of the warehouses and deleted from the other. The analysis covers order quantity (Q), number of orders per year (F), and safety level (S).

One-time costs to implement the consolidation and differences in transportation cost are not covered by this solution and must be handled separately. The analysis assumes that Q is calculated from the Wilson economic order quantity formula, $Q = \sqrt{\frac{2DA}{HV}}$, where D = annual demand in units, A = cost to order, H = annual cost to hold, expressed as a percent of unit price, and V = unit price. For simplification purposes, it is assumed that cost to order and cost to hold are the same at the two warehouses. The same methodology can be used to solve the problem when A and H are not equal at the two warehouses.

Let $D_1$, $D_2$, and $D_{12}$ = annual demands at supply depots 1, 2 and consolidated, respectively.

$Q_1$, $Q_2$, and $Q_{12}$ = order quantity at supply depots 1, 2 and consolidated, respectively.

$F_1$, $F_2$, and $F_{12}$ = annual number of replenishment orders at supply depots 1, 2 and consolidated, respectively, $= \frac{D_1}{Q_1}$, $\frac{D_2}{Q_2}$, and $\frac{D_{12}}{Q_{12}}$, respectively, n = ratio of demands between supply depot 2 and 1.

$$D_2 = nD_1$$

$$Q_1 = \sqrt{\frac{2D_1A}{HV}} = K\sqrt{D_1}, \text{ if A, H, and V are constants}$$

$$Q_2 = K\sqrt{D_2} = K\sqrt{nD_1}$$

$$Q_{12} = K\sqrt{D_1 + nD_1} = K\sqrt{D_1(1+n)}$$

B. <u>EFFECT ON ORDER QUANTITY</u>

<u>Quantity Savings</u>

The order quantity reduced by combining the order quantities of two different supply activities equals the sum of the order quantities at the two activities minus the combined order quantity.

$$= Q_1 + Q_2 - Q_{12}$$

$$= K\sqrt{D_1} + K\sqrt{nD_1} - K\sqrt{D_1(1+n)}$$

$$= K\sqrt{D_1}\left[1 + \sqrt{n} - \sqrt{1+n}\right]$$

<u>Percent Quantity Reduced</u>

The percentage by which the order quantity is reduced through combining is the quantity saved divided by the sum of the uncombined quantities times 100.

$$= \frac{Q_1 + Q_2 - Q_{12}}{Q_1 + Q_2}$$

$$= \frac{K\sqrt{D_1}\left[1 + \sqrt{n} - \sqrt{1+n}\right]}{K\sqrt{D_1} + K\sqrt{nD_1}}$$

$$= \frac{K\sqrt{D_1}\left[(1+\sqrt{n}) - \sqrt{1+n}\right]}{K\sqrt{D_1}\,(1+\sqrt{n})}$$

$$= 1 - \frac{\sqrt{1+n}}{1+\sqrt{n}}$$

C. <u>EFFECT ON NUMBER OF REQUISITIONS</u>

<u>Number Reduced</u>

The number of requisitions reduced each year by combining the orders from two supply activities is the sum of orders from the two activities minus the number of requisitions after combining.

$$= F_1 + F_2 - F_{12}$$

$$= \frac{D_1}{Q_1} + \frac{D_2}{Q_2} - \frac{D_{12}}{Q_{12}}$$

$$= \frac{D_1}{K\sqrt{D_1}} + \frac{nD_1}{K\sqrt{nD_1}} - \frac{D_1(1+n)}{K\sqrt{D_1(1+n)}}$$

$$= \frac{D_1}{K\sqrt{D_1}}\left[1 + \frac{n}{\sqrt{n}} - \frac{1+n}{\sqrt{1+n}}\right]$$

$$= \frac{\sqrt{D_1}}{K}\left[1 + \sqrt{n} - \sqrt{1+n}\right]$$

Percent Requisitions Reduced

The percent requisitions reduced annually is the number reduced divided by the previous uncombined number.

$$= \frac{F_1 + F_2 - F_{12}}{F_1 + F_2}$$

$$= \frac{\frac{\sqrt{D_1}}{K}\left[1 + \sqrt{n} - \sqrt{1+n}\right]}{\frac{D_1}{K\sqrt{D_1}} + \frac{nD_1}{K\sqrt{nD_1}}}$$

$$= \frac{\frac{\sqrt{D_1}}{K}\left[1 + \sqrt{n} - \sqrt{1+n}\right]}{\frac{\sqrt{D_1}}{K}\left(1 + \sqrt{n}\right)}$$

$$= 1 - \frac{\sqrt{1+n}}{1+\sqrt{n}}$$

D. EFFECT ON SAFETY LEVEL

Assume the demand during the leadtime L is a random variable $X_1$ on stock point 1, $X_2$ on stock point 2, and the demand on the consolidated stock point 12 is:

1. $$X_{12} = X_2 + X_1$$

2. Assume $nE(X_1) = E(X_2)$ and $b^2 Var(X_1) = Var(X_2)$

or $n\mu_{X_1} = \mu_{X_2}$ and $b^2\sigma^2_{X_1} = \sigma_{X_2}^2$

$$E(X_{12}) = E(X_1 + X_2) = E(X_1) + E(X_2)$$

$$\text{or} \quad \mu_{X_{12}} = \mu_{X_1} + \mu_{X_2} = (1+n)\mu_{X_1}$$

$$\mathrm{Var}(X_{12}) = \mathrm{Var}(X_1 + X_2) = \mathrm{Var}\ X_1 + \mathrm{Var}\ X_2 + 2\ \mathrm{Cov}(X_1, X_2)$$

where $n, b \geq 1$

3. Coef. of correlation $r = \dfrac{\mathrm{Cov}(X_1X_2)}{\sigma_{X_1}\ \sigma_{X_2}} = \dfrac{\mathrm{Cov}(X_1X_2)}{b\,\sigma_{X_1}^2}$

For

4. $r = +1 \quad \mathrm{Cov}(X_1X_2) = b\,\sigma_{X_1}^2$ direct relationship $X_1, X_2$

5. $r = 0 \quad \mathrm{Cov}(X_1X_2) = 0$ $X_1, X_2$ independent

6. $r = -1 \quad \mathrm{Cov}(X_1X_2) = -b\,\sigma_{X_1}^2$ inverse relationship

7. $\mathrm{Var}(X_{12}) = (1+b(b+2r))\sigma_{X_1}^2$ $\quad -1 \leq -(b^2+1)/2b \leq r \leq 1$

8. $= (1+b)^2\sigma_{X_1}^2$ for $r = 1$

9. $= (1+b^2)\sigma_{X_1}^2$ for $r = 0$

10. $= 0$ for $r = -(b^2+1)/2b \geq -1$

$= -1,\ b = 1$

Let $S_i$ represent the expected number of units in safety stock for the ith stock point. $S_i = ROP_i - \mu_{X_i} = k_i\ \sigma_{X_i}$

where $ROP_i$ is the reorder point and $k_i$ is the safety factor (in standard deviations of lead time demand) associated with the ith stock point.

The probability of running out of stock during a lead time is:

11. $$P(X_i > \mu_{X_i} + k_i \sigma_{X_i}) = \alpha_i \ , \ 0 \leq \alpha_i \leq 1$$

Assume we set the safety factors so that the probability of a stockout is the same for each stock point. (Note: the number of orders placed per unit of time, and thus the number of leadtimes experienced per unit of time, will differ among the stock points. This condition will be examined later.)

$$\text{For } \sigma_{X_{12}} \neq 0, \text{ or } r > -(b^2+1)/2b \geq -1$$

Let $P(X_1 > \mu_{X_1} + k_1 \sigma_{X_1}) = P(X_2 > \mu_{X_2} + k_2 \sigma_{X_2}) = P(X_{12} > \mu_{X_{12}} + k_{12} \sigma_{X_{12}})$

$= \alpha$.

Then $k_1 = k_2 = k_{12}$ (assuming all demand distributions are similar) and the safety stocks are

12. $$S_1 = k_1 \sigma_{X_1}$$

13. $$S_2 = k_2 \sigma_{X_2} = k_1 b \sigma_{X_1}$$

14. $$S_1 + S_2 = k_1 \sigma_{X_1} (1+b)$$

15. $$S_{12} = k_{12}\,\sigma_{X_{12}} = k_1\,\sigma_{X_1}\sqrt{1+b(b+2r)}$$

16. $$\frac{S_{12}}{(S_1 + S_2)} = \frac{\sqrt{1+b(b+2r)}}{1+b} \leq 1,\ r \leq 1$$

Thus for a given probability of stocking out, the level of safety stock (and its attendant holding cost) for the composite stock point will be less than or equal to the sum of the safety stocks (and their costs) of the individual stock points since the correlation coefficient is always less than or equal to one.

Another method of considering the effectiveness of the inventory system is to measure the expected number of shortage occurrences per year for the ith stock point:

17. $$ESO_i = \left(\frac{D_i}{Q_i}\right)\alpha_i$$

Where: $D_i$: expected yearly demand on stock point i

$Q_i$: economic lot size quantity for stock point i

18. $$Q_i = \sqrt{\frac{2AD_i}{HV}}$$

Where A = Ordering Cost, \$/order

H = Per unit holding charges/unit of inv./year

V = Unit cost of item, \$/unit

Assuming $D_2 = nD_1$, $D_{12} = D_1 + D_2 = (1+n)D_1$, and $\alpha_i = \alpha$ for i = 1, 2, 12,

$$\text{Then } Q_1 = \sqrt{\frac{2AD_1}{HV}} \qquad = \sqrt{\frac{2AnD_1}{HV}} = \sqrt{n}Q_1$$

19.
$$Q_{12} = \sqrt{\frac{2A(1+n)D_1}{HV}} = \sqrt{1+n}Q_1$$

$$ESO_1 = \left(\frac{D_1}{Q_1}\right)\alpha_1 \qquad ESO_2 = \left(\frac{nD_1}{\sqrt{n}Q_1}\right)\alpha_1 = \sqrt{n}\ ESO_1$$

20.
$$ESO_{12} = \left(\frac{D_{12}}{Q_{12}}\right)\alpha_{12} = \left(\frac{(1+n)D_1}{\sqrt{1+n}Q_1}\right)\alpha_1 = \sqrt{1+n}\ ESO_1$$

21.
$$\text{But } (ESO_1 + ESO_2) = (1+\sqrt{n})\ ESO_1 > \sqrt{1+n}\ ESO_1 = ESO_{12}$$

$$\frac{ESO_{12}}{(ESO_1 + ESO_2)} = \frac{\sqrt{1+n}}{1+\sqrt{n}} < 1, \quad n \geq 1$$

The above illustrates that for the same level of service $(1-\alpha)$ during a lead time, the expected number of shortage occurrences per year for the composite stock point will be less than the sum of the expected shortages per year of the individual stock points.

If we select $\alpha_{12}$ such that the expected number of yearly stockout occurrences for the composite stock point is the same as the sum of the expected shortage occurrences per year of the individual stock points (i.e., $ESO_1 + ESO_2 = (1+\sqrt{n})\left(\frac{D_1}{Q_1}\right)\alpha_1$ equals $ESO_{12} = \frac{(1+n)}{\sqrt{1+n}}\left(\frac{D_1}{Q_1}\right)\alpha_{12}$ from (21) and (20) above, then

22. $$\alpha_{12} = \frac{1+\sqrt{n}}{\sqrt{1+n}} \quad \alpha_1 > \alpha_1 \qquad\qquad n \geq 1$$

Expressions (22) and (11) imply that the safety factor $k_{12} < k_1 = k_2$. This implies the level of safety stock for the composite case (and the associated cost) is strictly less than the sum of the safety stocks (and their costs) of the individual stock points, i.e., for $\alpha_{12} = \frac{1+\sqrt{n}}{\sqrt{1+n}} \alpha_1$

23. $$S_{12} = k_{12}\,\sigma_{X_1} \sqrt{1+b(b+2r)} < (S_1+S_2) = k_1\,\sigma_{X_1}(1+b),$$

since $k_{12} < k_1$ and $\sqrt{1+b(b+2r)} \leq (1+b)$

We can also consider the effect on the number of expected backorders per year from replacing the individual stock points with a composite stock point.

Assuming the probability of a stockout during a leadtime is the same for all three stockpoints, the safety factors are equal and the number of expected backorders per lead time period for the ith stock point is:

24. $$EBO_i = \int_{\mu_{X_i}+k_i\,\sigma_{X_i}}^{\infty} (X_i - (\mu_{X_i} + k_i\,\sigma_{X_i})\;\; f_{X_i}(x_i)\,dx_i$$

$$EBO_i = \sigma_{X_i} \int_{k_i}^{\infty} (t-k_i)\; f(t)\,dt, \text{ where } t = (X_i - \mu_{X_i})/\sigma_{X_i}$$

25. $$EBO_2 = bEBO_1 \text{ and}$$

26. $$EBO_{12} = \sqrt{1+b(b+2r)}\ \ EBO_1, \text{ since } \sigma_{X_2} = b\sigma_{X_1},$$

$$\sigma_{X_{12}} = \sqrt{1+b(b+2r)}\,\sigma_{X_1} \text{ by 2), 7), and } k_{12} = k_1 = k_2.$$

The sum of the yearly expected backorders for the individual stock points is

27. $$SEBO_{1,2} = EBO_1 \left(\frac{D_1}{Q_1}\right) + EBO_2 \left(\frac{D_2}{Q_2}\right)$$

$$= EBO_i \left(\frac{D_1}{Q_1}\right) + bEBO_1 \left(\sqrt{n}\,\frac{D_1}{Q_1}\right)$$

$$= EBO_1 \left(\frac{D_1}{Q_1}\right)(1+ b\sqrt{n}) \quad \text{by 25) and 18)}$$

The sum of the yearly expected backorders for the composite stock point is

28. $$SEBO_{12} = EBO_{12} \left(\frac{D_{12}}{Q_{12}}\right) = \sqrt{1+b(b+2r)}\ EBO_1 \left(\sqrt{1+n}\right) \left(\frac{D_1}{Q_1}\right)$$

by 26), 18) and 19), and ratio of yearly expected backorders is

29. $$\frac{SEBO_{12}}{SEBO_{1,2}} = \frac{\sqrt{(1+n)(1+b(b+2r))}}{1 + b\sqrt{n}}$$

The composite stock point will provide a smaller number of yearly expected backorders (with a smaller level of safety stock) when the coefficient of correlation, $r < -(b-\sqrt{n})^2/2b(1+n)$

In summary, the composite stock point requires a smaller level of safety stock to provide the same probability of stocking out during a lead time period when the correlation coefficient is less than one. The composite stock point will also provide a smaller number of expected shortages per year than the individual stock points, for the same level of safety stock employed.

The composite stock point will provide a smaller number of yearly expected backorders, with a smaller level of safety stock, when the coefficient or correlation is less than $-(b-\sqrt{n})^2/2b(1+n)$.